

APPARATUS FOR AND METHOD OF TREATING A FLUID

CROSS REFERENCE TO RELATED APPLICATION

**[0001]** This application is a continuation-in-part of United States Patent Application Serial No. 10/206,976 filed July 30, 2002.

FIELD OF THE INVENTION

**[0002]** The present invention pertains to an apparatus for and a method of uniform treatment of fluid volumes using external irradiation sources. More particularly, the present invention pertains to an apparatus for and a method of treating a volume of fluid in a fluid passageway by irradiating the fluid passageway from an external irradiation source to provide a substantially uniform irradiation distribution within the fluid in the fluid passageway.

BACKGROUND OF THE INVENTION

**[0003]** During the irradiation treatment of fluids flowing through fluid passageways, the uniformity of irradiation is of primary importance. By way of example, the fluid might be treated with ultraviolet irradiation so as to disinfect, purify, or cause oxidation of material within the fluid. If the irradiation is not uniform, those portions of the fluid flowing through the regions of low irradiation intensity may be undertreated, while portions in the vicinity of peak irradiation fields may receive higher than desired doses of irradiation which could damage

material within the fluid. This problem is even more significant in the case of turbid fluids or fluids of high absorptivity for the applied irradiation.

**[0004]** Known techniques for irradiation of volumes of fluid include immersing multiple irradiation sources in the fluid. However, this is complex and costly, requiring multiple irradiation sources and introducing additional problems of cumulative absorption caused by impurities on the irradiation source-fluid interface. Cleaning mechanisms and processes have been proposed to overcome this last problem, but these are likewise elaborate and complex.

Potential irradiation source accidents introduce additional risks of pollution of the fluid and the distribution system by the hazardous irradiation source components.

**[0005]** A second approach is to restrict the fluid flow, avoiding underexposed volumes. This scheme suffers from limited efficiency, high pressure drops, and high cost of pumps necessary to achieve the desired flow.

**[0006]** Another approach is to introduce mixing devices in the fluid flow, in the hope that each portion of the fluid will receive an “average” treatment. This approach likewise suffers from efficiency problems, as well as the more serious problems of likely undertreatment of a portion of the fluid volume.

**[0007]** A further approach is to present the fluid as a thin film to the irradiation. This approach does not take into account the absorption of the source, the fluid passageway, and the fluid itself, nor the indices of refraction of the fluid passageway material or the fluid, and hence the real energy distribution in the thin film of fluid.

## SUMMARY OF THE INVENTION

**[0008]** The present invention is an apparatus for and a method of uniformly treating fluid volumes. In accordance with the present invention a fluid passageway is provided, through which the fluid flows. At least one source of irradiation, external to the fluid passageway, produces irradiation to irradiate the fluid flowing within the fluid passageway. The apparatus further includes a plurality of curved troughs for reflecting light from the at least one source of irradiation onto the fluid flowing within the fluid passageway. Each trough has a curved cross section, with a closed end, top and bottom edges, and an open end with first and second end edges. The open end of the first trough faces the open end of the second trough to define a space between the closed ends of the troughs. The top edges of the first and second troughs define a first plane, while the bottom edges of the first and second troughs define a second plane. A first set of reflectors joins the end edges of the first trough to the end edges of the second trough. Each reflector of the first set of reflectors has a top edge lying substantially in the first plane and a bottom edge lying substantially in the second plane. A second set of reflectors joins the top edges of the troughs and the top edges of the first set of reflectors and joins the bottom edges of the troughs and the bottom edges of the first set of reflectors. The first and second sets of reflectors and the troughs cooperate to define a substantially closed chamber. The fluid passageway passes through the chamber, and each source of irradiation is positioned in the chamber. At least one of the fluid passageway and the at least one source of irradiation is spaced from any focal axis of the troughs

so that the irradiation irradiating the fluid passageway is defocused. As a consequence, the fluid in the passageway is irradiated with a substantially uniform irradiation distribution, even in a fluid passageway of relatively large internal diameter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0009]** These and other aspects and advantages of the present invention are more apparent from the following detailed description and claims, particularly when considered in conjunction with the accompanying drawings. In the drawings:

**[0010]** Figure 1A is a sectional view, taken along line 1-1 in Figure 1B, illustrating a first embodiment of an apparatus and a method in accordance with the present invention;

**[0011]** Figure 1B is a perspective view, partially broken, of the apparatus of Figure 1A;

**[0012]** Figures 2A and 2B are, respectively, a sectional view and a partially broken perspective view illustrating a second embodiment of an apparatus and a method in accordance with the present invention, with Figure 2A taken along line 2-2 in Figure 2B;

**[0013]** Figures 3A and 3B are, respectively, a sectional view and a partially broken perspective view illustrating a third embodiment of an apparatus and a method in accordance with the present invention, with Figure 3A taken along line 3-3 in Figure 3B;

**[0014]** Figures 4A and 4B are, respectively, a sectional view and a partially broken perspective view illustrating a fourth embodiment of an apparatus and a method in accordance with the present invention, with Figure 4A taken along line 4-4 in Figure 4B;

**[0015]** Figures 5A and 5B are, respectively, a sectional view and a partially broken perspective view illustrating a fifth embodiment of an apparatus and a method in accordance with the present invention, with Figure 5A taken along line 5-5 in Figure 5B;

**[0016]** Figures 6A and 6B are, respectively, a sectional view and a partially broken perspective view illustrating a sixth embodiment of an apparatus and a method in accordance with the present invention, with Figure 6A taken along line 6-6 in Figure 6B;

**[0017]** Figure 7 illustrates a detection plane useful in determining irradiance patterns in an apparatus and method in accordance with the present invention;

**[0018]** Figures 8A-8H illustrate irradiance patterns on different detection planes in various apparatuses in accordance with the present invention; and

**[0019]** Figures 9 and 10 are sectional views illustrating further embodiments of an apparatus and method in accordance with the present invention.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

**[0020]** Figures 1A and 1B depict a first embodiment of an apparatus 20a in accordance with the present invention. Apparatus 20a includes a first curved reflecting trough 22 and a second curved reflecting trough 24. The curve of each

trough might be any second order curve, such as a parabola or an ellipse, or might be a combination of a parabolic closed end and elliptical sides. Likewise, each curve could be defined by a plurality of segments of second order curves or by a set of coordinates or in any other way. All that is required is that each trough reflect irradiation from a point within its curve toward the other trough. The curve may have one or more focal points, as in a second order curve, but that is not essential. Likewise, the curve may have a major axis and possibly a minor axis.

**[0021]** Each trough 22, 24 has a closed end, top and bottom edges 22a, 22b, 24a, 24b, and an open end. The top edges 22a, 24a define a plane, and the bottom edges 22b, 24b define a plane. The open end of each trough 22, 24 has two end edges 22c, 22d, 24c, 24d. The open ends of troughs 22 and 24 face each other to define a space having a longitudinal axis, which may be a major axis of a second order curve. End edges 22c, 22d of trough 22 are connected to the end edges 24c, 24d, respectively, of trough 24 by continuous flat reflectors 26, 28. Each flat reflector 26, 28 has a top edge 26a, 28a and a bottom edge 26b, 28b. Top edges 26a, 28a lie in the plane defined by top edges 22a, 24a, and bottom edges 26b, 28b lie in the plane defined by bottom edges 22b, 24b.

**[0022]** A flat reflector 30 joins the top edges 22a, 26a, 28a, 24a of trough 22, flat reflectors 26, 28, and trough 24. Another flat reflector (not shown) joins the bottom edges 22b, 26b, 28b, 24b of trough 22, flat reflectors 26, 28 and trough 24 and cooperates with troughs 22, 24 and flat reflectors 26, 28 and 30 to define a chamber 32.

**[0023]** A source of irradiation 34 is positioned within trough 22, and so within chamber 32. Irradiation source 34 might be a light source such as a source of ultraviolet light. By way of example, irradiation source 34 might be a microwave electrodeless discharge bulb, such as a tubular bulb, or might be an arc discharge bulb or a fluorescent discharge bulb. A fluid passageway 36 pass through chamber 32. Preferably, when irradiation source 34 is an elongated tube, fluid passageway 36 has a longitudinal axis that is parallel to the longitudinal axis of source 34. Fluid passageway 36 has an inlet end 36a, which is adapted to be connected to a source of fluid to be treated, and an outlet end 36b, which is adapted to be connected to a destination for the fluid after treatment.

**[0024]** If trough 22 or trough 24, or both, have a focal axis, then either irradiation source 34 or fluid passageway 36, or both, is spaced from all such focal axes. If desired, an adjustable mount can be provided making the position of irradiation source 34 or of fluid passageway 36, or both, adjustable. The mount might be adjustable on trough 22 or 24 or another mounting surface, or irradiation source 34 or fluid passageway 36 might be adjustable on the mount. As a consequence, the irradiation from source 34 is not focused on fluid passageway 36. Therefore, irradiation from source 34 irradiates the fluid within fluid passageway 36 with a substantially uniform irradiation distribution. The irradiation has a substantially two-dimensionally uniform irradiation distribution across the cross-section of fluid passageway 36, as well as a substantially three-

dimensionally uniform irradiation distribution within the volume of fluid in the fluid passageway.

**[0025]** Figures 2A and 2B depict a second embodiment of an apparatus 20b in accordance with the present invention. Apparatus 20b differs from apparatus 20a of Figures 1A-1B in that continuous flat reflectors 26 and 28 have been replaced by segmented flat reflectors 26c, 26d and segmented flat reflectors 28 and 28d, respectively, which are angled with respect to the longitudinal axis of apparatus 20b. Consequently, flat reflectors 26c and 26d meet at a V, as do flat reflectors 28c and 28d. Again, the irradiation from source 34 is defocused as it reaches fluid passageway 36, and so the irradiation has a substantially uniform distribution within the fluid in the passageway. The angled flat reflectors reflect the irradiation in a manner resulting in more uniform irradiance on the areas of fluid passageway 36 which are remote from irradiation source 34 by being  $\pm 90^\circ$  or more from the longitudinal axis of the space within chamber 32, including areas on the side of fluid passageway 36 opposite irradiation source 34.

**[0026]** Figures 3A and 3B depict a third embodiment of an apparatus 20c in accordance with the present invention. Apparatus 20c differs from apparatus 20a of Figures 1A-1B in that continuous flat reflectors 26 and 28 are replaced by curved reflectors 26e and 28e. Again, the curved reflectors 26e, 28e improve the uniformity of the radiation level on the area of fluid passageway remote from irradiation source 34.

**[0027]** Figures 4A and 4B depict a fourth embodiment of an apparatus 20d in accordance with the present invention. Apparatus 20d differs from apparatus



20a of Figures 1A-1B in that the troughs 22, 24 of apparatus 20d are spaced further apart along the longitudinal axis of apparatus 20d. For example, if troughs 22 and 24 are elliptical, each trough has a first focal axis within the trough and a second focal axis beyond the trough, and the second focal axes coincide. Continuous flat reflectors 26, 28 and 30, and a flat reflector joining the bottom edges of troughs 22 and 24 and reflectors 26 and 28 are provided, as in the apparatus 20a of Figure 1. Apparatus 20d has a first irradiation sources 34 which is at or adjacent the first focal point of trough 22 and a second irradiation source 38 which is at or adjacent the first focal point of trough 24. Fluid passageway 36 is at or adjacent the coincident second focal axes. Either the two irradiation sources 34, 38 are spaced from the first focal axes, or fluid passageway 36 is spaced from the second focal axes, or both. Because of this spacing, the irradiation from sources 34, 38 is defocused as it reaches fluid passageway 36, and so the irradiation has a substantially uniform distribution within the fluid in the passageway.

**[0028]** Figures 5A and 5B depict a fifth embodiment of an apparatus 20e in accordance with the present invention. Apparatus 20e differs from apparatus 20b of Figures 2A and 2B by having two irradiation sources 34, 38, in the same manner as apparatus 20d of Figures 4A-4B.

**[0029]** Figures 6A and 6B depict a sixth embodiment of an apparatus 20f in accordance with the present invention. Apparatus 20f differs from apparatus 20c of Figures 3A-3B by having two irradiation sources 34, 38, in the same manner as apparatus 20d of Figures 4A-4B.

**[0030]** Figure 7 illustrates a 45° detection plane 40 on which the irradiation within fluid passageway 36 is measured. Figures 8A-8H illustrate irradiation patterns on detection places at various angles within fluid passageway 36 in various of apparatuses in accordance with the present invention. These figures were obtained from computer simulations of the various apparatuses. Figure 8A illustrates the 45° irradiation pattern in an apparatus 20a of Figures 1A-1B having an elliptical reflector 22 and a parabolic reflector 24 and having a fluid passageway 36 with an internal diameter of 50 mm. As can be seen, the irradiation is substantially uniform over the width of the fluid passageway, resulting in a substantially uniform irradiation distribution within the fluid in fluid passageway 36.

**[0031]** Figure 8B illustrates the 45° irradiation pattern in an apparatus 20b of Figures 2A-2B having elliptical reflectors 22 and 24 and a fluid passageway 36 with an internal diameter of 50 mm. Again, the irradiation distribution is substantially uniform.

**[0032]** Figure 7C illustrates the 45° irradiation pattern in an apparatus 20d of Figures 4A-4B. The irradiation distribution is substantially uniform within the fluid in fluid passageway 36.

**[0033]** Figure 7D illustrates the 90° irradiation pattern in an apparatus 20d of Figures 4A-4B. The irradiation distribution is substantially uniform within the fluid passageway 36.

**[0034]** Figure 7E illustrates the 0° irradiation pattern in an apparatus 20d of Figures 4A-4B. Still, the irradiation distribution is substantially uniform within the fluid in fluid passageway 36.

**[0035]** Figure 7F illustrates the 0° irradiation pattern in an apparatus 20e of Figures 5A-5B with elliptical reflectors 22 and 24 and a fluid passageway 36 having an internal diameter of 70 mm. The irradiation distribution is again substantially uniform within the fluid in fluid passageway 36.

**[0036]** Figure 7G illustrates the 45° irradiation pattern in an apparatus 20e of Figures 5A-5B with elliptical reflectors 22 and 24 and a fluid passageway 36 having an internal diameter of 70 mm. The irradiation distribution is substantially uniform within the fluid in fluid passageway 36.

**[0037]** Figure 7H illustrates the 90° irradiation pattern in an apparatus 20e of Figures 5A-5B with elliptical reflectors 22 and 24 and a fluid passageway 36 having an internal diameter of 70 mm. Once again, the irradiation distribution is substantially uniform within the fluid in fluid passageway 36.

**[0038]** While apparatuses with two reflecting troughs have been illustrated and described above, any number N of troughs could be provided, with the longitudinal axis of each trough intersecting the longitudinal axis of its angularly adjacent troughs at an angle  $2\pi/N$ , where N is the number of troughs. By way of example, Figure 9 illustrates an apparatus having four reflecting troughs 22, 23, 24, 25 and four irradiation sources 34, 35, 38, 39. Each reflecting trough has a longitudinal axis 22', 23', 24', 25'. Each radiation source 34, 35, 38, 39 is at or adjacent the longitudinal axis 22', 23', 24', 25' of its respective trough.

Longitudinal axes 22' and 24' coincide, and longitudinal axes 23' and 25' coincide. The longitudinal axes intersect at a single intersection 42. Fluid passageway 36 is centered at or adjacent intersection 42. Either each irradiation source 34, 35, 38, 39 is spaced from its respective longitudinal axis 22', 23', 24', 25', or fluid passageway is centered slightly spaced from intersection 42, or both. As a result, the irradiation irradiates the fluid within passageway 36 with a substantially uniform distribution.

**[0039]** As a further example, Figure 10 illustrates an apparatus also having four reflecting troughs 22, 23, 24, 25 with longitudinal axes 22', 23', 24', 25'.

However, axes 22' and 24' do not coincide, although preferably they are offset in a direction substantially perpendicular to their longitudinal axes and so are parallel, and axes 23' and 25' do not coincide, but preferably also are offset in a direction substantially perpendicular to their longitudinal axes, and so are parallel. The longitudinal axes intersect within fluid passageway 36 at intersection 40a, 40b, 40c, 40d. Preferably, intersections 40a, 40b, 40c, 40d define a figure having a center of symmetry. Preferably, also, fluid passageway 36 has a longitudinal axis which passes through that center of symmetry. The irradiation is not focused within fluid passageway 36, and so a substantially uniform radiation distribution is obtained.

**[0040]** The present invention thus provides an improved apparatus for and method of treatment of fluids. Fluid can be treated by passing it through the fluid passageway of an apparatus in accordance with the present invention and irradiating the fluid with a substantially uniform irradiation distribution. Although

the invention has been described with reference to preferred embodiments, various alterations, rearrangements, and substitutions might be made, and still the result would be within the scope of the invention.